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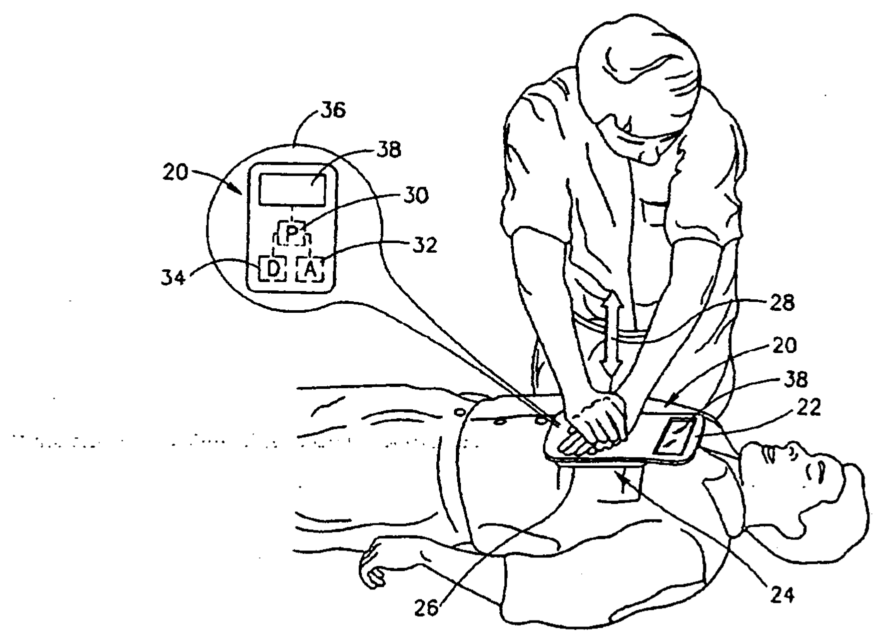
(54) Title: MONITORED CARDIOPULMONARY RESUSCITATION DEVICE



(57) **Abstract:** A method for determining displacement of a region of a patient s chest to which force is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising determining displacement of the chest region by double integrating over time acceleration of the chest region and correcting integration constants using information independent of the integration.

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MONITORED CARDIOPULMONARY RESUSCITATION DEVICE

FIELD OF THE INVENTION

The invention relates to cardiopulmonary resuscitation (CPR) devices and in particular to CPR devices that determine an amount by which the chest of a person undergoing CPR is compressed.

BACKGROUND OF THE INVENTION

Various devices are known in the art to assist a person, hereinafter a "rescuer", in properly administering CPR to a patient. US Patent 5,496,257, the disclosure of which is incorporated herein by reference, describes a device that is used in manually administering CPR to a patient. The device monitors aspects of CPR performed by a rescuer on a patient and provides information useful to the rescuer in performing the CPR. The device comprises a housing that is placed on the patient's chest, which the rescuer repeatedly presses and releases to alternately compress and decompress the patient's chest and heart so as to pump blood to the patient's body. The device comprises appropriate sensors for monitoring compression force applied to the chest, the number of compression-decompression cycles, hereinafter referred to as "CPR cycles", administered to the patient per minute. It also monitors blood flow. Information germane to the monitored parameters is presented to the rescuer on suitable audio and/or visual indicators comprised in the device. The rescuer can adjust his or her performance of the CPR, responsive to the presented information.

The patent notes that, optimally, a rescuer should "compress" a patient's chest between about 40 millimeters and about 50 millimeters during a compression phase of a CPR cycle. The patent further notes that some embodiments of the invention may comprise a "compression distance monitor" that detects "how far the patient's chest is compressed during a compression stroke" of a CPR cycle. However the patent does not provide information as to how such a distance monitor would be constructed or its operation.

PCT publication WO 99/25306, the disclosure of which is incorporated herein by reference, describes a CPR device comprising a cylinder fitted with a piston. When using the device to administer CPR to a patient, the cylinder is positioned on the patient's chest so that motion of the piston "up and down" in the cylinder is substantially perpendicular to the chest. A rescuer operating the CPR device applies his or her body weight to the piston via an appropriate support member coupled to the piston to move the piston up and down in the cylinder and apply a periodic force to the patient's chest that compresses the chest. In

accordance with some embodiments of the invention a pneumatic system is used to move the piston up and down inside the cylinder and assist the rescuer in performing the CPR.

The publication describes various sensors that may be attached to the CPR device to monitor performance of CPR on a patient and parameters indicative of the patient's condition during CPR. The publication notes that the CPR device may comprise a strap that surrounds the patient's chest and holds the CPR device in place on the chest. The strap may comprise a strain gauge useable to estimate displacement of the patient's chest during CPR. Alternatively or additionally the CPR device may comprise an accelerometer that measures an acceleration that can be integrated twice over time to determine chest displacement during CPR.

It is to be noted that the amount of blood moved through the heart during each CPR cycle during CPR is a function of the amount by which the volume of the heart is compressed and decompressed in the CPR cycle. A distance, hereinafter a "compression displacement", by which force applied to a region, hereinafter an "application region", of a patient's chest depresses the region during administration of CPR to the patient, is indicative of an amount by which the patient's heart is compressed. Compression displacement is therefore a parameter that is useful for monitoring CPR administered to a patient and in assisting a rescuer in performing CPR on the patient. Prior art methods of determining compression displacement during CPR do not generally provide measurements of compression displacement that are suitably accurate for monitoring and controlling CPR.

SUMMARY OF THE INVENTION

An aspect of some embodiments of the present invention relates to providing improved apparatus and methods for determining compression displacement of a patient undergoing CPR by double integrating over time measured acceleration of an application region of the patient's chest to which force is applied to administer the CPR.

An aspect of some embodiments of the present invention relates to determining times that are limits of integration for the integration of the measured acceleration. A time at which integration of acceleration begins is hereinafter referred to as an "integration onset time". An integration limit at which integration of acceleration ends is hereinafter referred to as an "integration termination time". A period of time between an integration onset time and its associated integration termination time is referred to as an “integration period”.

An aspect of some embodiments of the present invention relates to determining an initial value, hereinafter an "initial compression displacement", for a position of the application region at an integration onset time.

An aspect of some embodiments of the present invention relates to determining an initial value for a velocity, hereinafter a " compression velocity", of the application region at the integration onset time. The initial value for the compression velocity is referred to as an "initial compression velocity".

An aspect of some embodiments of the present invention relates to methods of periodically adjusting initial compression velocities used in performing double integration of acceleration so as to improve accuracy of compression displacements determined from the double integration.

An aspect of some embodiments of the present invention relates to methods of adjusting measurements of acceleration of the application region used in the double integration so as to improve accuracy of compression displacements determined from the double integration.

In accordance with an embodiment of the present invention, an integration period begins during each CPR cycle of a plurality of sequential CPR cycles administered to a patient. At the integration termination time of an integration period a difference, hereinafter an "integration difference" between compression displacement at two times, hereinafter first and second "reference times", during the integration period is determined. The compression displacement at at least one of the reference times is provided by the double integration. Optionally, one of the reference times is a time at a beginning of a CPR cycle for which compression displacement is known or is substantially equal to zero. Optionally, the first and second reference times are the integration onset and termination times.

The integration displacement difference is compared to a "reference displacement difference" which is a difference between compression displacements at the reference times that is determined using information independent of the integration. A difference between the integration displacement difference and the reference displacement difference, hereinafter an "integration error", is assumed to arise from an error in the initial compression velocity and/or acceleration measurements used during the integration period. The integration error is used to correct initial compression velocity and/or acceleration measurements during a next subsequent integration period.

The inventor has found that by regularly correcting initial compression velocities and/or acceleration measurements responsive to integration errors, in accordance with an embodiment of the present invention, double integration of acceleration over time can be used to provide values for compression displacement suitable for monitoring and controlling CPR.

In accordance with some embodiments of the present invention, force applied to compress a person's chest, hereinafter "CPR force", is measured and used to identify suitable integration onset and termination times, and reference times for which relatively accurate reference differences can be determined.

An aspect of some embodiments of the present invention relates to providing apparatus for determining compression displacement of a chest application region of a patient undergoing CPR.

There is therefore provided in accordance with an embodiment of the present invention a method for determining displacement of a region of a patient's chest to which force is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising:

a) determining an integration time period defined by and including an integration onset time and an integration termination time;

b) determining an initial displacement and an initial velocity for the chest region at the onset time;

c) measuring acceleration of the region caused by the force during the integration period;

d) calculating chest displacements for times during the integration period by double integrating the acceleration over time, wherein the determined initial velocity and displacement are used as constants of the integration;

e) determining a first difference between displacements at first and second times during the integration period using at least one of the calculated displacements;

f) determining a second difference between displacements at the first and second times independent of the calculated displacements;

g) determining a third difference equal to a difference between the first and second differences;

h) repeating a) through g) for a next integration period and including adjusting at least one of the initial velocity and or acceleration measurements responsive to the third difference.

Optionally determining an onset time for an integration period comprises determining an initial force that is applied to the region at a time at which compression of the chest is first beginning and determining the onset time to occur when force applied to the region is equal to the initial force plus a predetermined first threshold force.

Optionally the method comprises determining the first threshold force to have a value between 10 and 50 Newtons for force applied to the region manually.

Optionally the method comprises determining the first threshold force to have a value between 15 and 30 Newtons for force applied to the region manually.

Additionally or alternatively determining an initial velocity for a first integration period comprises determining the initial velocity to be equal to zero if the first threshold force is less than about 25 Newtons.

In some embodiments of the present invention the method comprises determining the first threshold force to have a value greater than 100 Newtons if force applied to the region is at least in part force generated by a CPR device.

In some embodiments of the present invention the method comprises determining the first threshold force to have a value greater than 150 Newtons if force applied to the region is at least in part force generated by a CPR device.

In some embodiments of the present invention, determining an initial velocity for a first integration period comprises determining the initial velocity to be equal to or greater than 100 mm/s if the threshold force is greater than 25 Newtons.

In some embodiments of the present invention, if the force at the threshold time is greater than a predetermined second threshold force, determining an initial displacement comprises determining a quotient equal to the force at the onset time divided by a spring constant that relates a magnitude of displacement of the region to a force applied to the region and setting the initial displacement equal to the quotient.

Optionally, for a first integration period the spring constant has a value between 5 and 20 Newton/mm.

Optionally, for a first integration period the spring constant has a value between 8 and 15 Newton/mm.

In some embodiments of the present invention, for an integration period subsequent to a first integration period, the spring constant is equal to an average of the spring constant for the preceding period and a spring constant which is equal to a quotient of a difference between

displacements at second and third times during the preceding integration period and a difference in forces applied to the region at the second and third times.

In some embodiments of the present invention, if the force at the onset time is equal to or less than the second threshold force, determining an initial displacement comprises setting the initial displacement equal to zero.

In some embodiments of the present invention the second threshold force is less than 30 Newtons.

In some embodiments of the present invention the second threshold force is less than 20 Newtons.

In some embodiments of the present invention adjusting acceleration measurements comprises determining an acceleration offset responsive to the third difference and subtracting the offset from the each of the acceleration measurements.

Optionally, for integration periods following a first integration period, determining an acceleration offset comprises setting the acceleration offset equal to an acceleration offset determined for an immediately preceding acceleration offset minus $\alpha(2E/T^2)$, where E is the third difference, T is elapsed time between the second and third time and α is a constant of proportionality.

In some embodiments of the present invention, adjusting the initial velocity comprises determining a velocity offset responsive to the third difference and subtracting the velocity offset from the initial velocity.

Optionally, for integration periods following a first integration period, determining a velocity offset comprises setting the velocity offset equal to a velocity offset determined for an immediately preceding integration period minus $\beta(E/T)$, where E is the third difference T is elapsed time between the first and second times and β is a constant of proportionality.

In some embodiments of the present invention, adjusting the initial velocity comprises determining a velocity offset responsive to the third difference and subtracting the velocity offset from the initial velocity.

Optionally, for integration periods following a first integration period, determining a velocity offset comprises setting the velocity offset equal to a velocity offset determined for an immediately preceding integration period minus $\beta(E/T)$, where E is the third difference T is elapsed time between the first and second times and β is a constant of proportionality.

Optionally, $\alpha+\beta=1$.

In some embodiments of the present invention, wherein β is greater than α.

In some embodiments of the present invention, β is greater than 0.5.

In some embodiments of the present invention, β is greater than 0.75.

In some embodiments of the present invention, α is greater than or equal to 0.5.

In some embodiments of the present invention the first time is equal to the integration onset time.

In some embodiments of the present invention the second time is equal to the integration termination time.

In some embodiments of the present invention the integration onset time for one integration period is the integration termination time of a previous integration period.

There is further provided, in accordance with an embodiment of the present invention, apparatus for determining displacement of a region of a patient's chest to which force is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising:

a surface that exerts force on a region of the patient's chest to depress the region;

an accelerometer that senses acceleration of the surface and generates signals responsive thereto;

a dynamometer that senses force between the surface and the chest region and generates signals responsive thereto;

a processor that receives the signals generated by the accelerometer which is programmed to process the signals and determine displacement in accordance with a method according to any of the preceding claims.

There is further provided, in accordance with an embodiment of the present invention CPR apparatus for performing CPR on a person comprising apparatus for determining displacement of a region of a patient's chest according to an embodiment of the present invention.

BRIEF DESCRIPTION OF FIGURES

Non-limiting embodiments of the present invention are described below with reference to figures attached hereto. In the figures, identical structures, elements or parts that appear in more than one figure are generally labeled with the same numeral in all the figures in which they appear. Dimensions of components and features shown in the figures are chosen for

convenience and clarity of presentation and are not necessarily shown to scale. The figures are listed below.

Fig. 1 schematically shows a rescuer manually administering CPR to a patient using a CPR device in accordance with an embodiment of the present invention; and

Fig. 2A and 2B show a flow chart of an algorithm by which a processor in the CPR device shown in Fig. 1 determines chest compression displacement during CPR in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EXAMPLES OF EMBODIMENTS

Apparatus for determining compression displacement, in accordance with embodiments of the present invention, comprises a surface, hereinafter referred to as a "pressure surface", which is pressed to a region, *i.e.* an application region, of the patient's chest to generate CPR force that compresses the chest. In some embodiments of the present invention, force is applied to the pressure surface manually. In some embodiments of the present invention, force applied to the pressure surface is generated manually with assistance from an apparatus such as apparatus described in PCT publication WO 99/25306 referenced above. In some embodiments of the present invention, force is applied to the pressure surface by appropriate automatic apparatus that is unassisted by force applied manually.

In accordance with embodiments of the present invention, the apparatus comprises at least one accelerometer that generates signals useable to determine acceleration of the pressure surface relative to the patient's back during administration of CPR. In some embodiments of the present invention, the apparatus comprises a force detector, hereinafter referred to as "dynamometer", that senses force, *i.e.* CPR force between the pressure surface and the patient's chest. Apparatus comprising an accelerometer and a dynamometer for determining compression displacement is described in Israel Application 138040, filed on August 23, 2000 by the same inventor as the inventor of the present application, the disclosure of which is incorporated herein by reference.

A processor receives signals generated by the dynamometer and the accelerometer responsive to force and acceleration that they respectively sense during administration of CPR to the patient. Optionally, the processor samples the signals from the dynamometer and accelerometer during CPR administration at regular time intervals determined by an appropriate sampling frequency.

In accordance with embodiments of the present invention, the processor processes samples that it receives to identify an integration onset time and begin a new integration period, optionally, during each CPR cycle of a plurality of CPR cycles applied to a patient. Optionally, the onset time occurs at a time near to or at the beginning of the CPR cycle, *i.e.* at the beginning of the CPR cycle's compression phase. At the onset time, the processor begins double integrating acceleration measurements generated from signals provided by the at least one accelerometer to determine values for compression displacement during the CPR cycle. Initial values for compression displacement and velocity at the onset time required for the double integration are determined responsive to the onset time and the way in which the onset time is determined, as discussed below.

Following the integration onset time, the processor processes samples that it receives to identify an integration termination time at which to terminate the integration. After termination of integration, the processor determines suitable first and second reference times from which a relatively accurate difference in compression displacement can be determined independent of compression displacement determined by the double integration. The processor determines a reference displacement difference responsive to the reference times and a corresponding integration displacement difference. The processor then compares the reference displacement difference to the integration displacement difference to determine an integration error.

In some embodiments of the present invention, the integration error is assumed to arise from an error in the initial compression velocity and/or in acceleration measurements acquired during the integration period. The integration error is then used to determine an error in the initial compression velocity and/or an error in acceleration measurements.

Optionally, the error in initial velocity is subtracted from the initial velocity used for the integration period to determine a new initial velocity that is used for the integration period of a next subsequent CPR cycle in the plurality of CPR cycles. Optionally, the error in acceleration measurements is assumed to be a constant that biases all acceleration measurements during the integration period. Optionally, the constant bias in acceleration measurements is used to determine a value for an "acceleration offset" that is subtracted from acceleration measurements during the integration period of the next CPR cycle.

In accordance with some embodiments of the present invention, integration onset and termination times are times for which a relatively accurate reference displacement difference

can be determined. For such embodiments, the onset and termination times are the first and second reference times. Hereinafter, it is assumed that the first and second reference times coincide respectively with the onset and termination times.

In some embodiments of the present invention, the processor uses CPR force to identify suitable integration onset and termination times and first and second reference times (which optionally coincide with onset and termination times) for which reference displacement differences can be relatively accurately determined.

A CPR cycle is generally characterized by an increasing CPR force during chest compression, and a decreasing force during subsequent chest decompression. CPR force increases from a minimum, generally equal to about zero if the rescuer is properly administering CPR, to a maximum, and then decreases back to the minimum. For CPR cycles for which compression displacement as a function of time is similar, same CPR forces for same stages of the cycles correspond to substantially same values of compression displacement. In addition, for times during CPR cycles for which chest mass and damping forces do not contribute substantially to determining CPR force, CPR force is generally substantially a function only of compression displacement. For these times, not only do same CPR forces correspond to same compression displacements, but a suitable "chest spring constant" for the human chest may be used to relate CPR force to compression displacement. (It is noted, that motion of the human chest during CPR may be modeled by motion of a damped spring, which has a spring constant corresponding to a "chest spring constant", to which an external force corresponding to CPR force is applied to compress and decompress the spring.)

From the above discussion it is seen that CPR force can be used to determine when a CPR cycle is beginning or ending by determining when CPR force turns around. CPR force can be used to identify times during administration of CPR at which compression displacement is the same and therefore times for which a reference displacement difference is substantially zero and an integration displacement difference should also be substantially zero. CPR force can also be used to provide a value for compression displacement assuming a value is known for a chest spring constant. (The trivial case for which CPR force is zero and therefore compression displacement is zero does not of course require a spring constant.) CPR force is therefore suitable for identifying, in accordance with embodiments of the present invention, integration onset and termination times.

In some embodiments of the present invention, an onset time for an integration period of a CPR cycle is determined to occur when CPR force during the compression phase of the CPR cycle first exceeds a predetermined threshold.

The inventors have found that CPR force and acceleration measurements can be erratic and/or may exhibit relatively large transients close to times at which CPR cycles begin (especially when mechanical apparatus is used to assist the CPR operation). At these times CPR force is at a minimum, generally substantially close to zero, and changing from a decreasing force characteristic of a decompression phase of a CPR cycle to an increasing force characteristic of a compression phase of a CPR cycle. By determining integration onset times at times for which CPR force crosses a suitable CPR force threshold, the onset times are constrained to occur at times that are displaced from times at which CPR cycles begin. For such "displaced" times, measurements of CPR force and acceleration are generally reliable.

The inventor has found that relatively small CPR force thresholds having values in a range from about 10 to 50 Newtons are generally sufficient and advantageous for CPR devices for which CPR force is generated only manually. For CPR devices for which CPR force is generated automatically by an appropriate apparatus or manually with assistance from a suitable apparatus, transients usually last longer and are larger than transients typical of some manually operated CPR devices. The inventor has found that for these CPR devices, generally relatively large CPR force thresholds having values in excess of about 100 Newtons are advantageous.

In accordance with an embodiment of the present invention, values for initial compression displacement and compression velocity that are required by the double integration are determined for a first CPR cycle of the plurality of CPR cycles responsive to values of the CPR force threshold. For a CPR threshold force that is relatively small and for which compression is negligible compared to a maximum advisable CPR force (about 500 Newtons), initial compression displacement and compression velocity for a first integration period are optionally assumed to be substantially equal to zero.

For values of CPR force threshold that are relatively large and for which compression displacement for a CPR force equal to the threshold is not negligible, an initial compression displacement is assumed to be equal to the CPR threshold force divided by a suitable chest spring constant. In some embodiments of the present invention, an initial value for a chest spring constant is assumed. Thereafter, the spring constant is optionally corrected responsive

to measurements of CPR forces at two different compression displacements. A difference in the CPR forces divided by a difference in the compression displacements provides an estimate of the spring constant. Preferably, measurements of the CPR forces are made at compression displacements for which compression velocity and acceleration are relatively small, *i.e.* close to extrema of compression displacement in the CPR cycle.

For integration periods subsequent to the first integration period, values for initial compression velocity are corrected responsive to the integration error, in accordance with an embodiment of the present invention as described above and in the discussion of Figs 2A and 2B below. Values for initial compression displacements of subsequent integration periods are the same as initial compression displacement for the first integration period as long as CPR cycles are substantially the same and each CPR cycle begins with a substantially same CPR force applied to a patient's chest. When CPR forces at the beginning of sequential CPR cycles are different, initial compression displacement is determined as described in the discussion of Figs. 2A and 2B.

The inventor has found that by adjusting initial compression velocity at the end of each CPR cycle as described above and in the discussion of figs. 2A and 2B, an error in an initial compression velocity used in a first CPR cycle is corrected after a first few CPR cycles following the first cycle. Accuracy of compression displacement determined by integration after one or two CPR cycles is therefore relatively insensitive to a value chosen for initial velocity of a first CPR cycle. The inventor has found that for small CPR threshold forces an initial velocity for a first integration period substantially equal to zero generally results in relatively rapid convergence to an accurate initial compression velocity. For large CPR threshold forces, values for initial compression velocity in a range from about 100 to about 400 mm/sec (about 2mm/sec per Newton of threshold force) are advantageous and result in relatively rapid convergence to an accurate initial compression velocity.

Fig. 1 schematically shows a rescuer manually administering CPR to a patient using, by way of example, a "manually operated" CPR device 20, in accordance with an embodiment of the present invention. Device 20 comprises a housing 22 and preferably a padded region 24 having a pressure surface 26. CPR device 20 is positioned on the patient's chest so that pressure surface 26 presses on a region, *i.e.* an application region, of the patient's chest appropriate for applying pressure to compress the chest and administer CPR. Motion that the

rescuer performs to alternately compress and decompress the chest while administering CPR is schematically indicated by double arrowhead icon 28.

CPR device 20 comprises a processor 30, an accelerometer 32 and a dynamometer 34, which are schematically shown with dashed lines in an inset 36 showing the CPR device. Accelerometer 32 senses acceleration of housing 22 and generates signals responsive thereto that it transmits to processor 30. It is assumed that the patient is lying on a hard surface and that therefore acceleration measurements provided by accelerometer 32 indicate acceleration of the patient's chest relative to his back. Were the patient lying on a relatively flexible surface, such as a surface of a flexible bed, an accelerometer in addition to accelerometer 32 would be positioned under the patient's back, preferably directly under accelerometer 32. For such a case, acceleration measurements provided by accelerometer 32 and the additional accelerometer would be used to determine acceleration of the patient's chest relative to his or her back. Dynamometer 34 senses force, *i.e.* CPR force, between pressure surface 26 and the patient's chest and generates signals responsive thereto, which it transmits to processor 30.

Processor 30 samples signals it receives from accelerometer 32 and dynamometer 34 at an appropriate sampling rate. It processes the sampled signals in accordance with an embodiment of the present invention, to determine a CPR force applied to the application region of the patient's chest and acceleration of the application region. Processor 30 uses the determined CPR forces and accelerations to determine compression displacement during each CPR cycle administered by the rescuer. In some embodiments of the present invention processor 30 samples signals that it receives and generates values for CPR force and acceleration at a sampling rate optionally between 500 and 1000 Hz. Optionally, processor 30 uses the sampled signals to determine a CPR cycle rate and cycle period.

In some embodiments of the present invention CPR device 20 comprises a visual display screen 38. Processor 30 generates a display of the determined CPR force and compression displacement on display screen 38 to cue the rescuer to his or her performance of the CPR. In some embodiments of the present invention the display of compression displacement and CPR force are presented graphically as sliding bar icons that increase and decrease in length in real time as compression displacement and CPR force increase and decrease. In some embodiments of the present invention processor 30 also displays CPR cycle rate.

In some embodiments of the present invention CPR device 20 comprises an input terminal (not shown), such as a keyboard generated by the processor on the visual display, for receiving instructions and or data from a rescuer using the CPR device. In some embodiments of the present invention, by way of example, the rescuer uses the input terminal to transmit data regarding a patient that is used by processor 30 to determine appropriate ranges for CPR force, maximum compression displacement and/or CPR cycle rate. In some embodiments of the present invention, processor 30 generates a visual alarm or an audio alarm if during administration of CPR a parameter for which a range is determined does not lie in its determined range.

Figs. 2A and 2B show a flow chart of an example of an algorithm 50, in accordance with an embodiment of the present invention, by which processor 30 of CPR device 20 determines compression displacement from sampled force and acceleration signals that it receives from dynamometer 34 and accelerometer 32.

CPR device 20 comprises a memory (not shown) stored with constants to be used by algorithm 50. Among the stored constants are, optionally, a CPR force threshold "F_{th}", an initial value for a chest spring constant "K_o" and an initial value for compression velocity "V_o".

For values of force threshold F_{th} that are relatively small (about 20 Newtons or less), an initial compression displacement S_o for use in the algorithm and initial compression velocity V_o are optionally set equal to zero. For values of the force threshold F_{th} greater than about 20 Newtons, an initial value for compression displacement S_o is determined by dividing F_{th} by the chest spring constant K_o. For force thresholds in excess of about 20 Newtons, initial compression velocity V_o is, optionally, assigned a value between 100 and 400 mm/s. As noted above, for manual CPR devices relatively small values for F_{th} are appropriate while for automatic CPR devices relatively large values for F_{th} are appropriate. Since, by way of example, CPR device 20 is a manually operated device, it is assumed that F_{th} is relatively small.

In a block 52 of the flow chart, a rescuer operating CPR device 20 turns on the CPR device. For convenience, block 52 lists some of the variables that are optionally stored in the memory for use by algorithm 50 in determining CPR compression. Optionally, in a following block 54, processor 30 calibrates CPR device 20.

During calibration, which may take less than 500 milliseconds, the rescuer has not yet begun administering CPR. CPR device 20 is preferably upright and either on the floor or in position on the patient with pressure pad 24 (Fig. 1) on the patient's chest. In some embodiments of the present invention, calibration comprises sampling force and acceleration signals from dynamometer 34 and accelerometer 32 a plurality of times and determining an average acceleration "A_a" and an average force "F_a" from the samples.

In some embodiments of the present invention, values of force and acceleration measurements during calibration are pre-stored in the memory. In a block 56, processor 30 determines whether or not the determined averages A_a and F_a and data spreads are within their respective normative ranges. In a decision block 58, if A_a, F_a or the data spread during calibration is outside its respective normative range, the processor branches to a block 60 and generates a signal indicating that CPR device 20 is not operable and requires appropriate user attention. If A_a, F_a and the data spread during calibration are within their respective normative ranges, processor 30 determines that CPR device 20 is functioning properly.

Processor 30 stores the value for F_a and initializes an indexed variable $A_{off}(0)$ to the value for A_a. F_a is subsequently used to correct force measurements provided by dynamometer 34 during CPR and $A_{off}(0)$, which is updated during CPR as discussed below, is subsequently used to correct acceleration measurements provided by accelerometer 32.

Following successful calibration, in a block 62, processor 30 generates a signal that indicates to the rescuer that the CPR device is operable and ready for administration of CPR.

In some embodiments of the present invention, processor 30 then pauses before proceeding and waits until the rescuer indicates, for example by depressing an appropriate button on an input terminal of the CPR device, that he or she is about to start administering CPR. After receiving indication of initiation of CPR, processor 30 proceeds to block 64. In some embodiments of the present invention processor 30 proceeds directly to block 64 upon successful completion of calibration.

In block 64 processor 30 initializes two "integer-counting indices", "I" and "J" by setting both indices equal to zero. I counts the number of times signals from dynamometer 34 and accelerometer 32 are sampled during a CPR cycle subsequent to successful calibration. J counts the number of CPR cycles that have been administered to the patient since calibration. In the present algorithm, by way of example, a single integration period begins in each CPR

cycle. As a result, J also counts the number of integration periods that have occurred since calibration.

In block 64 processor 30 also sets a logical variable, "SEARCH", equal to "YES" and initializes a variable "F_{min}" by setting the variable equal to $F_{o\ min}$. Optionally, $F_{o\ min}$ has a value in a range from 100-200 Newton. The value of the logical variable is used to determine whether or not processor 30 searches for an integration onset time of an integration period of a CPR cycle. F_{min} is used to identify when compression force begins to increase following a decompression phase of a CPR cycle, thus indicating that a new CPR cycle is beginning. F_{min} is re-initialized and then updated during each CPR cycle.

Processor 30 then advances to a block 66 in which it increments index I by one and proceeds to a block 68. In block 68 processor 30 samples signals from dynamometer 34 and accelerometer 32 and determines respectively, responsive to the sampled signals, a force, *i.e.* a CPR force, between pressure surface 26 and the patient's chest and an acceleration of pressure surface 26. A force "reading" and an acceleration reading determined responsive to the I-th sampling of signals from dynamometer 34 and accelerometer 32 during the J-th integration period are denoted as F(I,J) and A(I,J) respectively. A time at which readings F(I,J) and A(I,J) are made is referred to as a "time I".

Processor 30 proceeds to a block 69 and corrects acceleration reading A(I,J) responsive to $A_{off}(J)$ and force reading F(I,J) responsive to F_a. In some embodiments of the present invention, the correction to A(I,J) is accomplished by setting $A(I,J) = A(I,J) - A_{off}(J)$. The correction to F(I) is accomplished by setting $F(I,J) = F(I,J)-F_a$.

In a decision block 70, if SEARCH is equal to "YES", which at this stage in the history of the example it is, processor 30 proceeds to a block 71 in which processor 30 determines if $F(I,J) < F_{min}$ and if it is, then processor 30 sets $F_{min} = F(I,J)$. Processor 30 then proceeds to a block 72 in which it determines whether time I at which force and acceleration readings F(I,J) and A(I,J) are taken is a suitable integration period onset time for the (J+1)-th integration period. In some embodiments of the present invention, processor 30 determines that time I is a suitable onset time for the (J+1)-th integration period if $F(I,J) \geq (F_{th} + F_{min})$.

If, in decision block 72, processor 30 determines that I is not a suitable integration onset time then the processor proceeds to decision block 73. In decision block 73 processor 30 determines which way to branch dependent upon a value of J. If J = 0, no CPR cycle has been

administered or is as yet in process since the time at which calibration has been successfully completed, and a first integration period has not begun. Processor 30 then returns to block 66, increments I by one and acquires new force and acceleration readings (block 68) which are corrected (block 69) and tested (block 72) to determine if there is an integration onset time for an integration period in the first CPR cycle. Processor 30 continues looping through blocks 66 to 72 until it locates in block 72 an integration onset time in the first CPR cycle. Optionally, as processor 30 loops through block 66 to 72 looking for onset of the first CPR cycle it displays on visual display 38 a compression displacement determined by dividing F(I,J) by the spring constant K_o.

Upon finding an integration onset time, processor 30 advances to block 74 and "turns off" the search for an integration onset time by setting logical variable SEARCH equal to no. Processor 30 then advances to a block 76 and increments J by one, i.e. J=J+1, which at this point in the history of the example, results in a value for J equal to one.

Processor 30 then proceeds to a block 78 to in which processor 30 sets up for the J-th integration period, which at this point is for the first, J=1, integration period. In block 78 processor 30 determines values for acceleration offset variable, $A_{off}(J)$. For J=1 (the present case) processor 30 sets $A_{off}(J) = A_{off}(0)$, which is equal to A_a.

In block 78, processor 30 also determines an initial compression displacement and initial compression velocity for the J-th integration period. Let compression displacement and compression velocity at a time I for the J-th integration period be represented by S(I,J) and V(I,J) respectively. Let $S_o(J)$ and $V_o(J)$ represent respectively initial values for compression displacement and compression velocity for the J-th integration period. For J=1, in block 78 processor 30 sets $S_o(J) = S_o$ (which is equal to $(F_{min}+ F_{th})/K_o$) and $V_o(J)=V_o$.

Processor 30 then advances to a block 84 in which the processor calculates chest velocity and compression displacement at time I in accordance with integration expressions of the form $V(I,J) = Vo(J)+\Delta T[A(I,J)+A(I-1,J)]/2$ and $S(I,J) = S(I-1,J)+\Delta T\ [V(I,J)+V(I-1,J)]/2$. In the expression for V(I,J) and S(I,J), ΔT is a sample period, *i.e.* a time lapse between reading of force and acceleration taken at time I-1 and at time I. In some embodiments of the present invention, signals from dynamometer 34 and accelerometer 32 are sampled at a constant sampling frequency. If "f" represents the sampling frequency then $\Delta T = 1/f$. In some embodiments of the present invention, values for compression force F(I,J) and compression displacement S(I,J) determined by processor 30 are displayed in real time and processor 30

proceeds to block 86 and displays S(I,J) and F(I,J) on visual display 38. Processor 30 then advances to a decision block 88. In block 88 processor 30 determines when to begin looking for a next onset time of an integration period subsequent to the one that is currently being performed.

In some embodiments of the present invention, a subsequent integration period is expected to begin immediately upon completion of a current integration period. Completion of the current integration period and onset of the next integration period occurs in a CPR cycle that follows the CPR cycle in which the current integration period began. (In the present algorithm, by way of example, an integration termination time of an integration period is assumed to coincide with an integration onset time of a next integration period. Processor 30 therefore does not search for an integration termination time of an integration period but searches instead only for a next onset time.)

In some embodiments of the present invention, processor 30 begins to search for indications of an integration onset time of a subsequent integration period at times close to a time at which a CPR cycle and its associated integration period are expected to come to an end. In some embodiments of the present invention an "imminent" end of a CPR cycle is anticipated by noting when force readings indicate that a CPR cycle is in its decompression phase.

In some embodiments of the present invention, processor 30 begins searching for an integration onset time of a subsequent integration period following a suitable time lapse after the integration onset time of a current integration period. In some embodiments of the present invention, the time lapse is a predetermined time lapse. In some embodiments of the present invention the time lapse is equal to a fraction less than one of an expected CPR period. CPR cycles are usually performed at a rate of between 80-100 CPR cycles per minute. An expected duration of a CPR period and an integration period is therefore known. An expected CPR period can also be estimated from a rate at which a rescuer performs CPR cycles.

In some embodiments of the present invention, processor 30 starts searching for onset of a subsequent CPR cycle following a time lapse after onset of a current CPR cycle that is equal to about one half of an expected CPR period. In algorithm 50, by way of example, following display block 86, processor 30 proceeds to a decision block 88. In decision block 88, if less than one half of an expected CPR cycle period has elapsed since the onset of the current cycle (at this point the first CPR cycle) processor 30 branches back to block 66. At

block 66 processor 30 increments I by one, advances to block 68 to acquire new readings of acceleration and force and corrects the readings in block 69. At block 70 processor 30 skips to block 84 to calculate a next value for S(I,J). As long as less than one half of a CPR cycle has elapsed, processor 30 repeatedly loops back to block 66 from block 88 and at block 70 skips to block 84 to update compression displacement during the CPR cycle.

However, if more than one half of a CPR period has elapsed since onset of the current integration period, at decision block 88, processor 30 advances to a block 90, instead of looping back to block 66. In block 90 processor 30 "turns on" a search for an onset time of a next integration period by setting logical variable SEARCH equal to "Yes". Processor 30 then proceeds to a block 92 in which, if F_{min} has not been "re-initialized" during the current "J-th" integration period and $F(I,J) \leq F(I-1,J)$ (i.e. the current CPR cycle "J" is in a decompression phase) processor 30 re-initializes F_{min} by setting F_{min} equal to F(I,J). Processor 30 then loops back to block 66, takes new samples of A(I,J) and F(I,J) and continues to block 70. As a result of the value to which SEARCH is set in block 90, when processor 30 reaches block 70 it no longer proceeds to block 84 after acquiring and correcting readings of acceleration and force. Instead processor 30 continues on to block 72 to test if force readings indicate onset of a next integration period.

In block 72 processor 30 tests to determine whether or not $F(I,J) \geq (F_{th} + F_{min})$. The condition is first satisfied only after F(I,J), and as a result F_{min}, has stopped decreasing and F(I,J) has begun to increase and exceeds F_{min} by the threshold F_{th}. It is noted that after initialization during a J-th integration period, F_{min} decreases during the integration period as long as F(I,J) decreases and stops decreasing once F(I,J) begins to increase. F_{min} does not increase when F(I,J) starts increasing. A value of F_{min}, when it stops decreasing, is a minimum in the CPR force at which CPR force the rescuer ends decompressing the patient's chest in the J-th CPR cycle and begins compressing the patient's chest in the (J+1)-th CPR cycle. F_{min}, when it stops decreasing is a "turnaround" CPR force at which the J-th CPR cycle ends and the (J+1)-th CPR cycle begins. (As noted above, in some embodiments of the present invention, the onset of the (J+1) integration period does not necessarily coincide with the termination time of the J-th integration period.) The condition $F(I,J) \geq (F_{th} + F_{min})$ requires that the (J+1)-th integration period corresponding to the (J+1) CPR cycle begins only after CPR force during the cycle has exceeded the turnaround CPR force F_{min} by the threshold force F_{th}.

If processor 30 determines that F(I) does not satisfy $F(I,J) \geq (F_{th} + F_{min})$ a new integration onset time has not been found and the processor, as before, advances to decision block 73. However, in decision block 73 for $J \neq 0$, *i.e.* after the first integration period has begun, processor 30 branches to block 84 rather than back to block 66 and uses the acceleration reading acquired in block 68 to update compression displacement V(I,J) and S(I,J) for the current J-th integration period.

If on the other hand, in block 72 processor 30 determines that F(I,J) satisfies $F(I,J) > (F_{th} + F_{min})$ then, the processor determines that the J-th integration period has ended and an integration onset time for the next (the (J+1)) integration period has been located. Processor 30 advances to block 74, and turns off the search for a next onset time. In block 76 processor 30 increases J by 1 and proceeds to block 78 to "set up" for the (J+1) integration period and determine values for $A_{off}(J+1)$, $V_o(J+1)$ and $S_o(J+1)$.

In block 78 processor 30 also determines a reference displacement difference, an integration displacement difference and an integration error "E" for the J-th integration period for two suitable reference times of the integration period. Processor 30 optionally uses E to determine values for $A_{off}(J+1)$, $V_o(J+1)$.

For example, assume that reference times for the J-th integration period are the onset time and termination time of the J-th period (which is the onset time of the (J+1) integration period). Assume further that CPR force F(I,J) at the onset time is substantially equal to CPR force at the termination time. If F_{min} of the CPR cycles J and (J-1) are equal, compression displacement at the onset and termination times could then be assumed to be substantially equal and a reference displacement difference for the onset and integration times would then be equal to zero. The integration displacement difference for the J-th integration period is equal to the compression displacement determined by double integration of acceleration at the integration termination time, less the compression displacement $S_o(J)$ at the onset time of the J-th integration period. For this case the integration error E is equal to the integration displacement difference since the reference displacement difference is equal to zero.

Let T represent a time lapse between the reference times, which in our example would be the time lapse between the onset and termination times. In some embodiments of the present invention, it is assumed that the error E is generated by an error in $V_o(J)$ and/or a constant spurious addition to acceleration readings A(I,J) acquired during the integration cycle. In some embodiments of the present invention, a portion of the error is ascribed to the

error in $V_o(J)$ and a portion is ascribed to an error in acceleration readings $A(I,J)$. In particular, if α is the portion of E ascribed to acceleration readings, and β is the portion of E ascribed to an error in initial velocity V_o, then $A_{off}(J+1) = A_{off}(J)-\alpha(2E/T^2)$ and $V_o(J+1) = V_o(J)-\beta(E/T)$. Since in this example the reference displacement difference is equal to zero, processor 30 determines that $S_o(J+1) = S_o(J)$.

It is noted that whereas in the above discussion it is assumed that the reference displacement difference is zero the reference displacement difference can often be different from zero. If F_{min} for the onset time of the J-th integration period is not equal to F_{min} at the onset time of the (J+1) integration period, CPR forces will not be equal at the onset and termination times of the J-th integration period. (CPR forces at the onset and termination times will in general be different if for example a rescuer sometimes does and sometimes does not completely decompress a patient's chest during CPR). As a result, compression displacement at the onset time can be assumed to be ***different*** from compression difference at the termination time and a reference displacement difference will not be equal to zero.

The inventor has found that generally it is advantageous β to be greater than α. In some embodiments of the present invention, $\alpha + \beta = 1$. In some embodiments of the present invention β is greater than 0.5. In some embodiments of the present invention β is greater than or equal to 0.75.

A value for $S_o(J+1)$ in block 78 is determined by the force F(I,J) at the new onset time and the value for the chest spring constant "K(J)" at the end of the J-th integration period. Optionally, $S_o(J+1)= F(I,J)/ K(J)$

In accordance with an embodiment of the present invention, the value of the spring constant which was initialized to K_o is updated during each CPR cycle. If K(J) represents the spring constant the end of the J-th CPR cycle then, in accordance with an embodiment of the present invention, $K(J+1)=[K(J)+ \Delta F(J)/ \Delta D(J)]/2$. In the expression for K(J+1), $\Delta D(J)$ equals a difference between compression displacement at first and second times during the J-th CPR cycle and $\Delta F(J)$ equals a difference between CPR force at the first and second times. The inventor has found that a practical initial value K_o for the chest spring constant is about 10 Newton/mm.

After determining $A_{off}(J+1)$, $V_o(J+1)$ and $S_o(J+1)$, processor 30 advances to block 84 to commence double integrating acceleration for the J+1 integration cycle.

In some embodiments of the present invention, processor 30 determines when a rescuer has ceased performing CPR in order to ventilate a patient's lungs, *e.g.* by applying mouth to mouth resuscitation. In some embodiments of the present invention, the processor recognizes that the rescuer has stopped applying CPR for a short "ventilation break" when a new onset integration time is not found within a predetermined time period following identification of a last onset time. In some embodiments of the present invention the predetermined time is greater than about 1.5 CPR cycle periods. When a ventilation break is identified, processor 30 returns to block 64 and begins searching for an onset time for a first integration cycle following the ventilation break.

It is noted that whereas determining compression displacement has been described for a manual CPR device, methods and apparatus for determining compression displacement in accordance with the present invention are not restricted to manual CPR devices. For both manual assist and automatic CPR devices, in accordance with embodiments of the present invention, compression displacement is determined similarly to the manner in which compression displacement is determined for the manual CPR device described above.

In some manual assist CPR devices and automatic CPR devices in accordance with some embodiments of the present invention, the processor controls application of CPR force to the chest of a patient responsive to chest compression and a measure of the patient's response to the CPR. For example, assume that an automatic CPR device, in accordance with an embodiment of the present invention, comprises a sensor that sense blood flow in a patient undergoing CPR performed by the CPR device. The processor might control force, generally within appropriate limits, to increase chest compression if chest compression is less than a predetermined value and if the sensed blood flow is less than desired.

It is noted that in some embodiments of the present invention, for periods of a CPR cycle for which accurate values for compression displacement are not required, such as during the decompression phase of a CPR cycle, compression displacement is determined from the spring constant. For such embodiments an integration period ends at a time when compression displacement begins being used to determine compression displacement and an integration termination time of one integration period does not coincide with an integration onset time of a next integration period. For such embodiments, optionally, an integration termination time is determined to coincide with a time close to a time at which compression displacement is a maximum. Identification of the maximum can be performed, for example by searching for a

maximum force using a technique similar to that used for searching for a minimum force as described above but using a variable "Fmax" instead of F_{min} and increasing F_{max} each time F(I,J) is greater than Fmax.

In the description and claims of the present application, each of the verbs “comprise”, “include” and “have”, and conjugates thereof, are used to indicate that the object or objects of the verb are not necessarily a complete listing of members, components, elements or parts of the subject or subjects of the verb.

The present invention has been described using detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the present invention utilize only some of the features or possible combinations of the features. Variations of embodiments of the present invention that are described and embodiments of the present invention comprising different combinations of features noted in the described embodiments will occur to persons of the art. The scope of the invention is limited only by the following claims.

CLAIMS

1. A method for determining displacement of a region of a patient's chest to which force is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising:

a) determining an integration time period defined by and including an integration onset time and an integration termination time;

b) determining an initial displacement and an initial velocity for the chest region at the onset time;

c) measuring acceleration of the region caused by the force during the integration period;

d) calculating chest displacements for times during the integration period by double integrating the acceleration over time, wherein the determined initial velocity and displacement are used as constants of the integration;

e) determining a first difference between displacements at first and second times during the integration period using at least one of the calculated displacements;

f) determining a second difference between displacements at the first and second times independent of the calculated displacements;

g) determining a third difference equal to a difference between the first and second differences;

h) repeating a) through g) for a next integration period and including adjusting at least one of the initial velocity and or acceleration measurements responsive to the third difference.

2. A method according to claim 1 wherein determining an onset time for an integration period comprises determining an initial force that is applied to the region at a time at which compression of the chest is first beginning and determining the onset time to occur when force applied to the region is equal to the initial force plus a predetermined first threshold force.

3. A method according to claim 2 and comprising determining the first threshold force to have a value between 10 and 50 Newtons for force applied to the region manually.

4. A method according to claim 2 and comprising determining the first threshold force to have a value between 15 and 30 Newtons for force applied to the region manually.

5. A method according to claim 3 or claim 4 wherein determining an initial velocity for a first integration period comprises determining the initial velocity to be equal to zero if the first threshold force is less than about 25 Newtons.

6. A method according to claim 2 and comprising determining the first threshold force to have a value greater than 100 Newtons if force applied to the region is at least in part force generated by a CPR device.

7. A method according to claim 2 and comprising determining the first threshold force to have a value greater than 150 Newtons if force applied to the region is at least in part force generated by a CPR device.

8. A method according to any of claims 3-7 wherein determining an initial velocity for a first integration period comprises determining the initial velocity to be equal to or greater than 100 mm/s if the threshold force is greater than 25 Newtons.

9. A method according to any of claims 2-7 wherein if the force at the threshold time is greater than a predetermined second threshold force, determining an initial displacement comprises determining a quotient equal to the force at the onset time divided by a spring constant that relates a magnitude of displacement of the region to a force applied to the region and setting the initial displacement equal to the quotient.

10. A method according to claim 9 wherein for a first integration period the spring constant has a value between 5 and 20 Newton/mm.

11. A method according to claim 9 wherein for a first integration period the spring constant has a value between 8 and 15 Newton/mm.

12. A method according to any of claims 9-11 wherein for an integration period subsequent to a first integration period, the spring constant is equal to an average of the spring constant for the preceding period and a spring constant which is equal to a quotient of a

difference between displacements at second and third times during the preceding integration period and a difference in forces applied to the region at the second and third times.

13. A method according to any of claims 9-12 wherein if the force at the onset time is equal to or less than the second threshold force, determining an initial displacement comprises setting the initial displacement equal to zero.

14. A method according to any of claims 9-13 wherein the second threshold force is less than 30 Newtons.

15. A method according to any of claims 9-13 wherein the second threshold force is less than 20 Newtons.

16. A method according to any of claims 1-15 wherein adjusting acceleration measurements comprises determining an acceleration offset responsive to the third difference and subtracting the offset from the each of the acceleration measurements.

17. A method according to claim 16 wherein for integration periods following a first integration period, determining an acceleration offset comprises setting the acceleration offset equal to an acceleration offset determined for an immediately preceding acceleration offset minus $\alpha(2E/T^2)$, where E is the third difference, T is elapsed time between the second and third time and α is a constant of proportionality.

18. A method according to any of claims 1-16 wherein adjusting the initial velocity comprises determining a velocity offset responsive to the third difference and subtracting the velocity offset from the initial velocity.

19. A method according to claim 18 wherein for integration periods following a first integration period, determining a velocity offset comprises setting the velocity offset equal to a velocity offset determined for an immediately preceding integration period minus $\beta(E/T)$, where E is the third difference T is elapsed time between the first and second times and β is a constant of proportionality.

20. A method according to claim 17 wherein adjusting the initial velocity comprises determining a velocity offset responsive to the third difference and subtracting the velocity offset from the initial velocity.

21. A method according to claim 20 wherein for integration periods following a first integration period, determining a velocity offset comprises setting the velocity offset equal to a velocity offset determined for an immediately preceding integration period minus $\beta(E/T)$, where E is the third difference T is elapsed time between the first and second times and β is a constant of proportionality.

22. A method according to claim 21 wherein $\alpha+\beta=1$

23. A method according to any of claims 20-22 wherein β is greater than α.

24. A method according to any of claims 19-22 wherein β is greater than 0.5.

25. A method according to any of claims 19-22 wherein β is greater than 0.75.

26. A method according to any of claims 17, 20-22 wherein α is greater than or equal to 0.5.

27. A method according to any of the preceding claims wherein the first time is equal to the integration onset time.

28. A method according to any of the preceding claims wherein the second time is equal to the integration termination time

29. A method according to any of the preceding claims wherein the integration onset time for one integration period is the integration termination time of a previous integration period.

30. Apparatus for determining displacement of a region of a patient's chest to which force

is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising:

a surface that exerts force on a region of the patient's chest to depress the region;

an accelerometer that senses acceleration of the surface and generates signals responsive thereto;

a dynamometer that senses force between the surface and the chest region and generates signals responsive thereto;

a processor that receives the signals generated by the accelerometer which is programmed to process the signals and determine displacement in accordance with a method according to any of the preceding claims.

31. CPR apparatus for performing CPR on a person comprising apparatus according to claim 30.

32. A method for determining displacement of a region of a patient's chest to which force is applied so as to cyclically compress and decompress the chest and administer thereby CPR to the patient comprising:

determining initial values for displacement and velocity of the chest region;

acquiring acceleration measurements of the chest region;

determining displacement of the chest region by double integrating the acceleration measurements over time using the values of the initial displacement and velocity as integration constants;

acquiring measurements of displacement independent of the double integration; and

adjusting at least one of the initial velocity and acceleration measurements responsive to displacement of the chest region determined by the integration and the independent measurements of displacement.

33. A method according to claim 32 wherein acquiring measurements of displacement independent of the double integration comprises;

measuring magnitude of the force applied to the chest region;

determining a chest spring constant that relates an amount by which the chest region is compressed to the magnitude of the force; and

determining a displacement of the chest region independent of the integration that is substantially equal to the chest spring constant and a measured magnitude of the force.

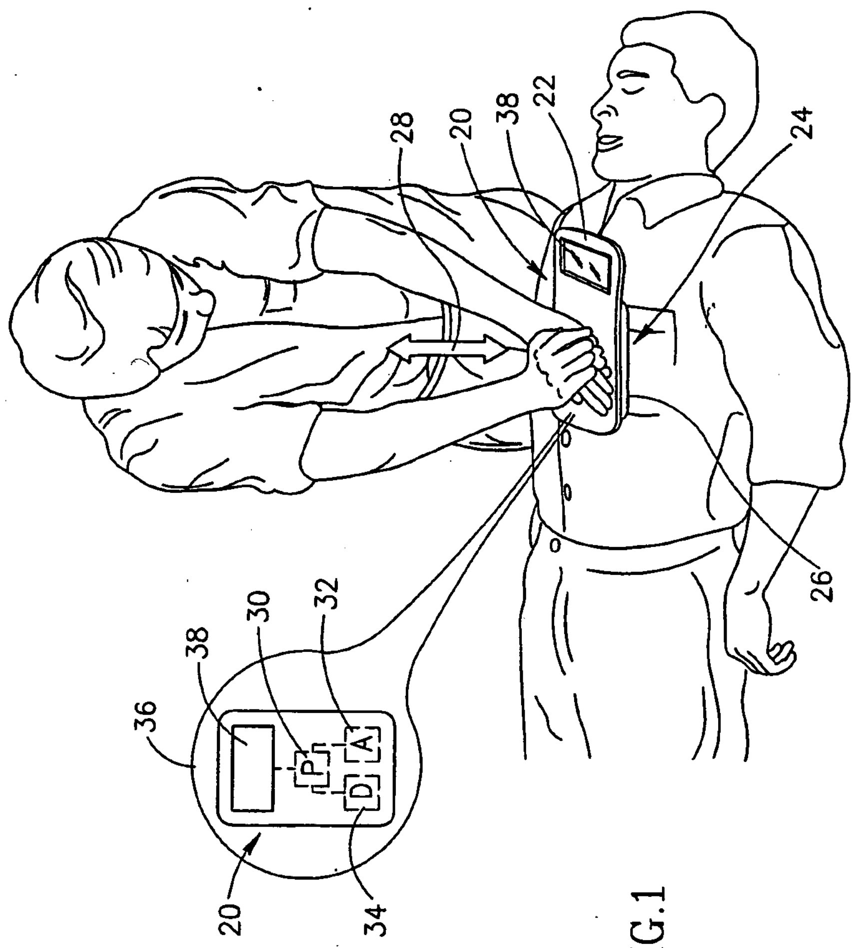

FIG.1

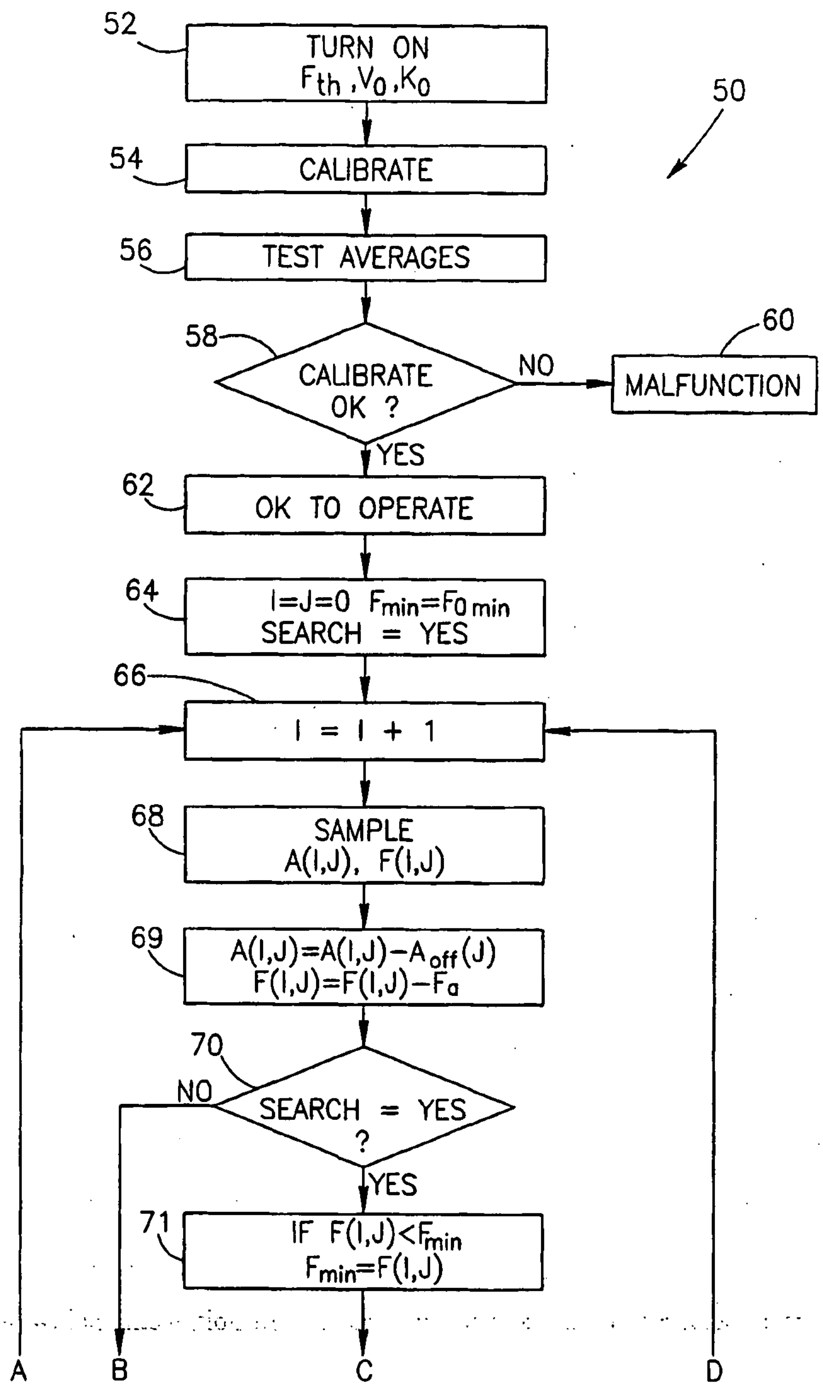
52
TURN ON
Fth ,V0 ,K0
50
54
CALIBRATE
56
TEST AVERAGES
58
CALIBRATE
OK ?
NO
60
MALFUNCTION
YES
62
OK TO OPERATE
64
I=J=0 Fmin=F0 min
SEARCH = YES
66
I = I + 1
68
SAMPLE
A(I,J), F(I,J)
69
A(I,J)=A(I,J)−Aoff(J)
F(I,J)=F(I,J)−Fa
70
NO
SEARCH = YES
?
YES
71
IF F(I,J)<Fmin
Fmin=F(I,J)
A
B
C
D

FIG.2A

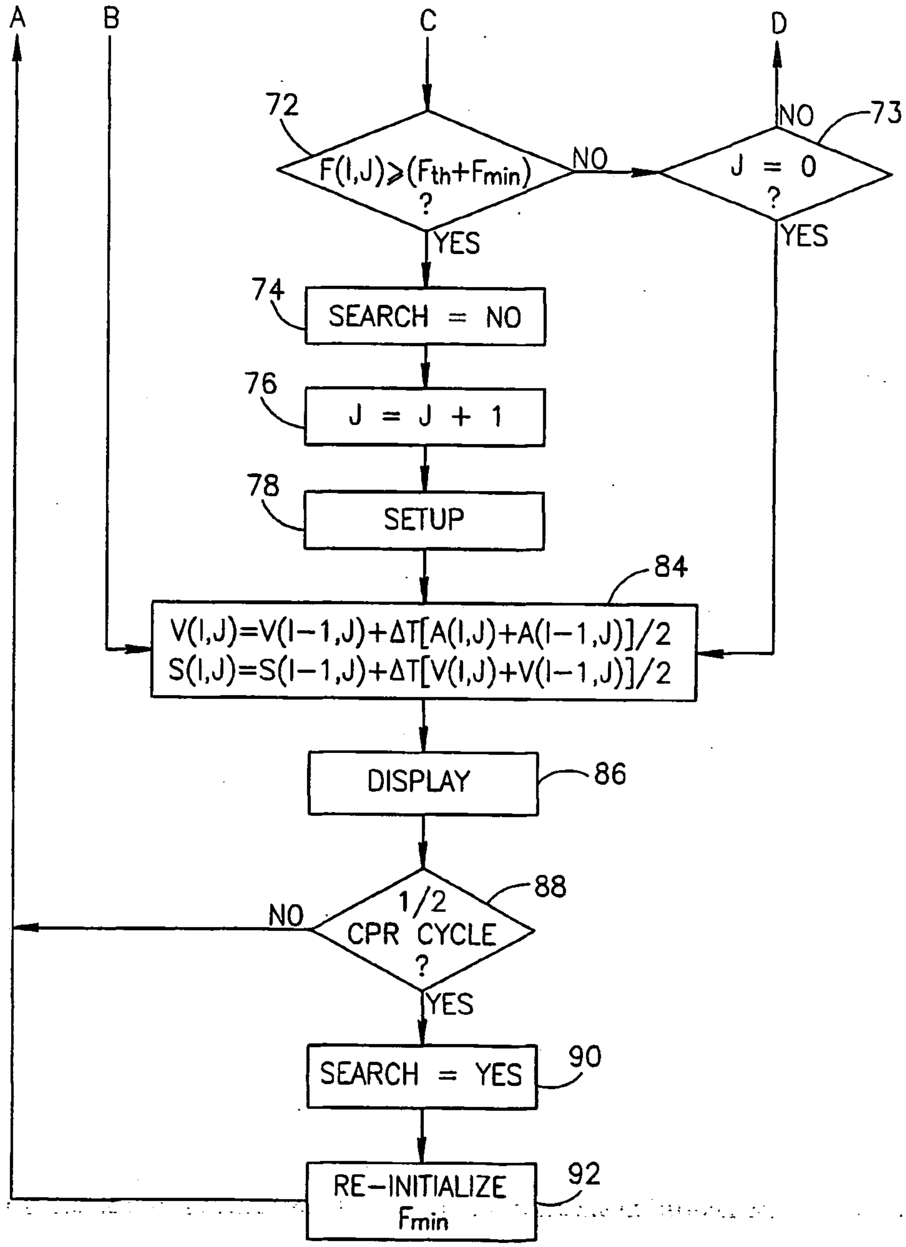
A
B
C
D
72
F(I,J)≥(Fth+Fmin)?
NO
YES
73
J = 0 ?
NO
YES
74
SEARCH = NO
76
J = J + 1
78
SETUP
84
V(I,J)=V(I−1,J)+ΔT[A(I,J)+A(I−1,J)]/2
S(I,J)=S(I−1,J)+ΔT[V(I,J)+V(I−1,J)]/2
DISPLAY
86
88
1/2 CPR CYCLE ?
NO
YES
SEARCH = YES
90
RE−INITIALIZE Fmin
92

FIG.2B